REMARKS

In the office action, the examiner rejected claims 1-28 as obvious over Farmer (U.S. Patent No. 6,106,561) and Augut, Edwards and Aziz (hereinafter, "Edwards"), "Flexible streamline grids for reservoir simulation," Stanford University – Petroleum Engineering Dept. (1998). Applicants respectfully traverse the examiner's rejection of said claims, and request that the examiner re-examine and reconsider the application in the light of the following comments.

Applicants contend that the examiner has misunderstood the teachings of Farmer and Edwards, or the teachings of the present application, or both.

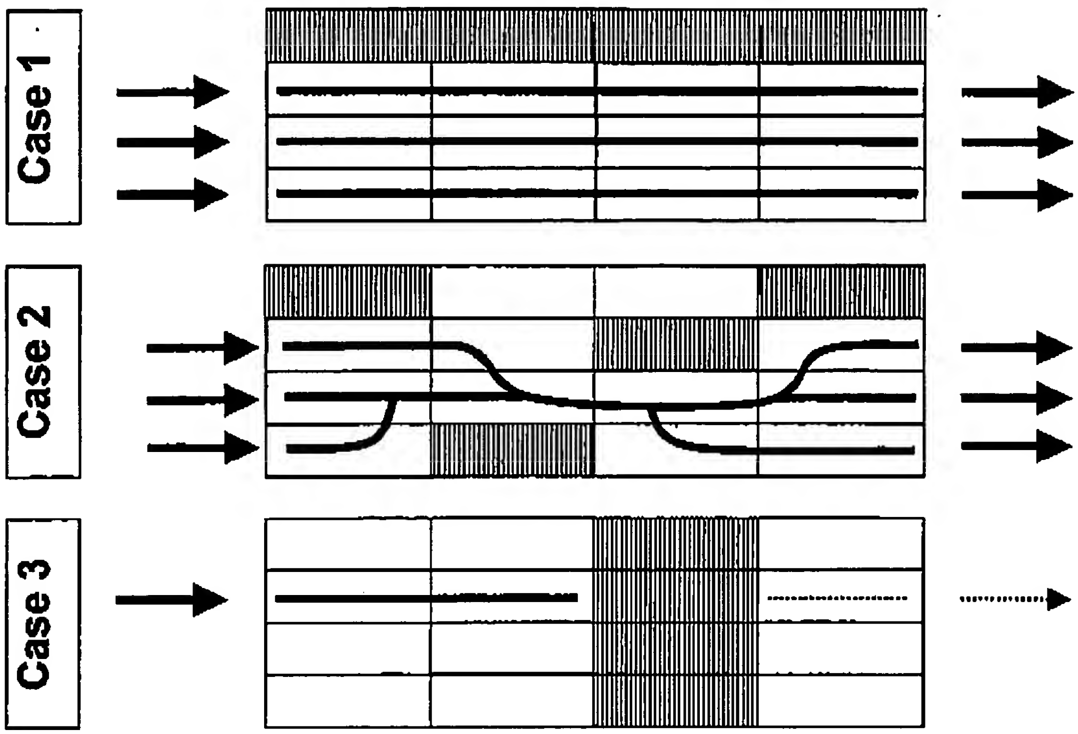
Some background information on the field and subject matter of the present application and the two prior art references will be useful. Two main concepts are involved. One is gridding, and the other is upscaling, or scale up.

Gridding. In the field of reservoir simulation, it is necessary to subdivide the reservoir into discrete cells, which is called gridding. Gridding is done in basically one of two ways: structured or unstructured. In structured gridding, each cell is the same and has four sides (viewed in two dimensions from above). In unstructured gridding, the cells vary in size and shape, and may be polygons of any number of sides. Structured grids are computationally simpler, but unstructured grids have the advantage of being able to honor structural features as they exist in nature. Unstructured grids also handle wells better. Smaller cells can be used in the vicinity of wells to better handle the larger changes in flow rate caused by wells.

Upscaling The data used in reservoir simulation computations come from geologic models, which provide information in great detail, i.e., on a very fine grid. To simulate the behavior of an entire petroleum reservoir, a much coarser grid is needed; otherwise, the calculations would take too much time and computer capability. Therefore, the geologic model data must be scaled up to a coarse grid. It is important that the scale up be as accurate as possible in representing, on a coarser scale, the detailed fine-scale data. Types of upscaling in

use fall basically into one or the other of two categories: direct averaging or flow-based scale-up. In direct averaging, permeability values are collected from each fine-grid cell within a coarse-grid cell, and averaged in a straightforward, numerical way to yield the value of permeability for the coarse-grid cell. By contrast, flow-based scale-up is a much more sophisticated process. In essence, the flow equations are solved for smaller grid domains of the fine grid, and from these solutions effective properties of the cell are computed for the coarse grid. Flow-based scale-up yields better permeability values than direct averaging, but flow-based scale-up is more computationally intensive.

Permeability is a measure of resistance to flow through the pores of a rock. It is a dynamic property and requires a flow-based technique for accurate scale-up. A major shortcoming of direct averaging is that it is independent of spatial distribution of permeability and leads to inaccurate answers in many cases. This is illustrated in the figure on the next page which shows a comparison of upscaled permeability using arithmetic averaging or simple mean (a form of direct averaging) and flow-based scale-up for three cases. Each case has a grid of sixteen fine cells which correspond to one coarse cell. The shaded cells have been assigned a value of zero permeability. The unshaded cells have a value of unit permeability. The flow paths are shown with arrows. The table below the figure shows upscaled permeability using the two upscaling methods. Although the flow paths in the three cases are very different due to different arrangement of permeability values, direct averaging gives the same answer in each case. Direct averaging gives the correct answer for Case 1, overestimates permeability in Case 2, and completely fails in Case 3. This is particularly troubling in Case 3 where the zero permeability cells form a complete barrier to flow but are completely disregarded by direct averaging. The flow-based scale-up gives the correct answer in each case taking into account, the spatial distribution of permeability. Therefore, direct averaging cannot be trusted for general use with the numerous permeability distributions found in oil reservoirs. The illustrations show a structured grid for simplicity. The same concepts apply to unstructured grids where the need for flow-based scale-up is just as great, but the problem is much more difficult to solve and is the subject of the present application.



Direct Averaging *vs.* Flow-Based Scale-Up

Upscaled Permeability (k_e) Calculations		
Case	Arithmetic Averaging	Flow-Based Scale-Up
1	0.75	0.75
2	0.75	$0 < k_e < 0.75$
3	0.75	0

Reservoir simulation requires both grid generation and scaling up. Both structured and unstructured gridding are known and used. Similarly, both direct averaging and flow-based scale-up are known and used. However, to the best of Applicants knowledge, the combination of unstructured grids and flow-based upscaling has not been taught or offered for sale in commercial software products due to the difficulty of finding a workable way to combine the more computationally difficult grid with the more computationally difficult scale-up method. The present application fills this need. The following table summarizes the state of development of these two aspects of reservoir simulation.

	Direct Averaging	Flow-Based Scale-Up
Structured Gridding	Known	Known
Unstructured Gridding	Known	Unknown and subject of Present Application

Farmer discloses a structured gridding method for reservoir simulation application, as clearly stated in his title and abstract. This patent is the basis for the software product "Flogrid." Flogrid has an unstructured gridding capability option, and this is also discussed in the '561 patent (it is called Petragrid) although seemingly unrelated to the inventive aspects of the disclosure which all pertain to structured grids. Flogrid includes an upscaler (block 70 in some of the Farmer patent's flow charts). Farmer discusses the upscaler beginning at column 43, line 13. Farmer's upscaler is capable of doing either direct averaging or flow-based averaging. The key point, however, is that Farmer discloses no way to use flow-based scale-up in conjunction with unstructured gridding. This can be easiest seen by examining Farmer's drawings. Figs. 14c, 16 and 24 all show both the unstructured gridder module 40c1 and the upscaler module 70, but none show any input path connecting the unstructured gridder to the upscaler, as contrasted to the direct arrow between the structured gridder module 68 and the upscaler. In fact, Applicants have a licensed copy of Flogrid, and know from first-hand experience that the flow-based scale-up option in particular cannot be used with the unstructured gridding option.

In terms of the steps in Applicants' claim 1, Farmer does not teach or suggest steps (c)-(e). In step (c), the flow equations are solved for the computational grid. As specified in step

(a), the computational grid is an unstructured grid. Solving the flow equations is a step that is needed in flow-based upscaling but not in direct averaging upscaling. As shown above, Farmer does not disclose how flow-based upscaling can be done for unstructured grids. Therefore, Farmer does not teach or suggest Applicants' step (c).

Step (d) of Applicants' claim 1 uses the fluxes and pressure gradients computed in step (c) to calculate average values of those quantities for the coarse-scale grid (which is also specified in the claim preamble to be unstructured). This step is neither taught nor suggested in Farmer because this is a further step in the process of flow-based scale up in an unstructured grid framework, which is not addressed in Farmer or Flogrid. Step (e) completes the scaling-up process. From step (c) on, the scaling up is restricted to flow-based upscaling. (One doesn't need fluxes and pressure gradients for the fine-scale grid if one is going to upscale by direct averaging.) Since the claim preamble and step (a) specify that both fine and coarse grids are unstructured, then from step (c) on, Applicants' method moves into areas unknown from reading Farmer. The reason that it is unknown and unaddressed in Farmer is because it is difficult to conceive of how to use flow-based upscaling with unstructured grids, which suggests why Applicants filed a patent application on their solution to this problem.

Applicants' other independent claims are claims 20 and 25. Both claims have many similarities to claim 1. Claim 25 is restricted to a certain, preferred way of designing the fine grid so that it will be similar to the coarse grid, making the upscaling computation easier. For structured grids, this is simple, but it is not simple for unstructured grids. Applicants disclose a preferred way of doing this, and claim 20 is limited to that embodiment or group of embodiments. From the discussion of claim 1, it can readily be seen that claim 20 is also a method of upscaling using unstructured grids. At a minimum, steps (c)-(f) are neither taught nor suggested in Farmer because they embody flow-based upscaling being done on unstructured grids.

For Edwards to disclose what is not disclosed in Farmer, Edwards would have to teach how to do flow-based upscaling on unstructured grids. Edwards teaches no such thing. The

Edwards paper is about generating unstructured grids (Edwards calls them "flexible" grids). As Edwards states in his Abstract, "This report addresses both the generation of suitable simulation grids for heterogeneous media and specific discretization issues that arise with such grids." Edwards looks at various flexible grid approaches, and attempts to determine which give the best results. His examples use the various grids in reservoir simulations. Edwards does not exactly state what upscaling method has been used in the examples, but there are strong suggestions on pages 10 and 23 that it is "power law averaging," which is consistent with the reference to "conventional upscaling methods" on page 14. On page 10, he states, "Currently, power law upscaling is used to define the coarse curvilinear grid permeability field from fine scale rock data." On page 23, he states, "No attempt has been made in this work to study the crucial problem of upscaling." This admission alone is sufficient to dispose of the Edwards paper as an obviousness reference in combination with Farmer. Edwards goes on to add, "There is a need for development of a robust full tensor upscaling algorithm applicable to general polygons in two and three dimensions."

The "power-law" upscaling Edwards refers to as being in current use (although not taught or explained in Edwards) is a form of direct averaging. This can actually be confirmed from Farmer, columns 44-45. Farmer uses the term "simple averaging" methods for the term "direct averaging" used herein. Farmer's Eq. 6 is a form of power averaging. It is the simple volume average, over the fine grid cells of the permeability raised to a power ω. The concept is similar to the well-known rms (root-mean-square) average in electrical applications, where $\omega = 2$. As Farmer states at column 44, lines 31-33, in simple averaging methods, the averaging formula is not justified by reference to an approximate flow solution. Although Farmer does not use the term flow-based upscaling, that is what he is referring to in the last part of that sentence to contrast with simple averaging methods. Edwards's reference on page 23 to a full-tensor upscaling algorithm applicable to general polygons is presumably a call for the development of flow-based upscaling on unstructured grids. Certainly "general polygons" means unstructured grids. Attention is directed to page 13 of the present application, where the formulation of Applicants' method begins with the full permeability tensor in Eq. 1. Applicants simplify by neglecting the off-diagonal elements, reducing to a scalar formulation. The scalar formulation is

more practical and more common in reservoir simulation (with structured grids). Edwards is somewhat unrealistic in calling for full-tensor upscaling for unstructured grids, when the difficult scalar formulation had not been done until the present application.

The examiner cites Edwards for disclosing solving flow equations representing a porous medium, which teaching the examiner finds lacking in Farmer although the examiner believes this would be inherent to the Flogrid program. It is not clear to Applicants which step in Applicants' method (for example, in Applicants' claim 1) the examiner is referring to. Any simulator program solves the flow equations at some point. What is done in Applicants' step (c) is to solve the flow equation within the cells on the fine grid to obtain fluxes and pressure gradients that are then used in steps (d) and (e) to calculate effective values of the permeability that are better coarse grid estimates than can be obtained by direct averaging. Once one has permeability values for the coarse grid, then the simulation process involves solving flow equations on the coarse grid. This (i.e., solving the flow equations on the coarse grid) is done in any reservoir simulator program, but is not what is occurring in step (c). As explained above, what is specified in Applicants' steps (c)-(e) is neither taught nor suggested by either Farmer or Edwards.

Because Applicants believe all independent claims are non-obvious, it follows that if this is true, none of Applicants' dependent claims can be obvious.

CONCLUSION

Each of the claims of the application is limited to Applicants' inventive method for upscaling permeability for unstructured grids. Each of these claims is believed to be patentably distinct from all known prior art, including all art cited by the examiner. Therefore, Applicants respectfully request allowance of all pending claims.

Applicants respectfully traverse the examiner's rejection of claims 1-28 and request that the examiner reexamine and reconsider the application in light of the foregoing comments.